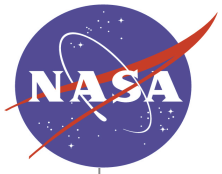

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Interferometer System Overview

Gary Blackwood

Interferometer Systems Manager

October 14, 2003

Interferometer Systems

Terrestrial Planet Finder Mission

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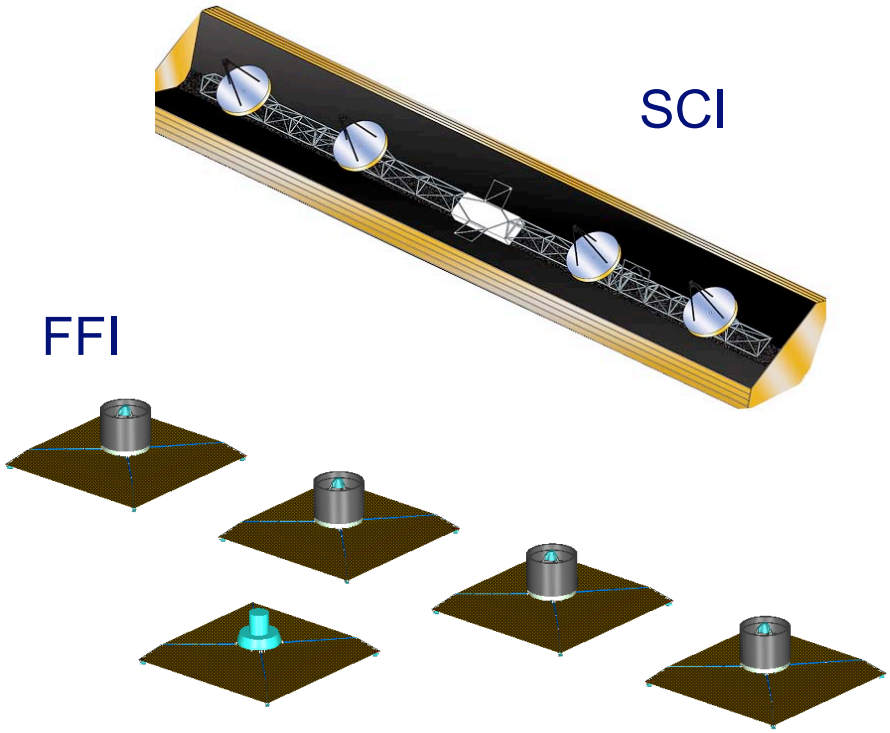


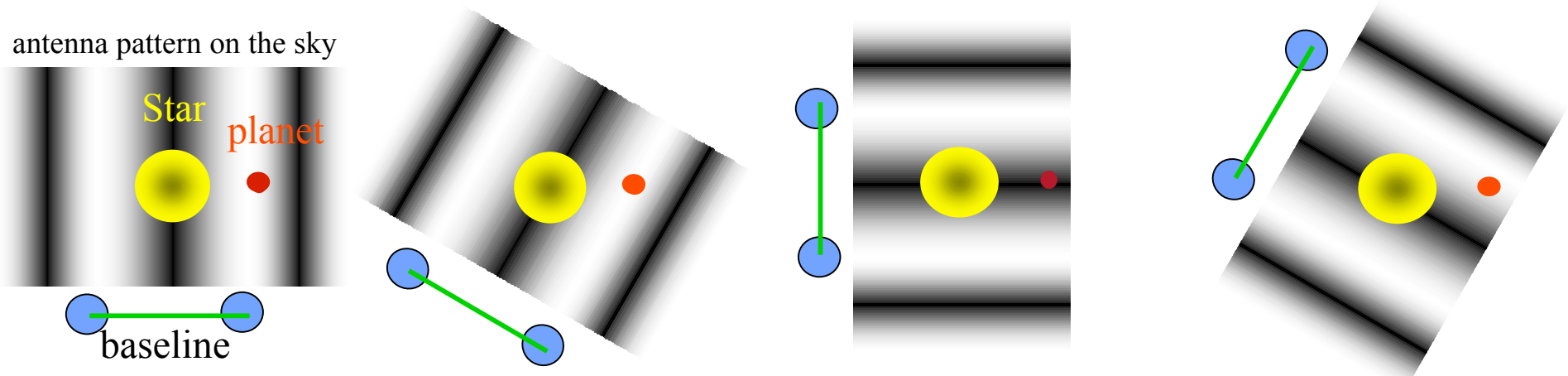
How:

- Architecture Team
- Design Team
- Technology Teams

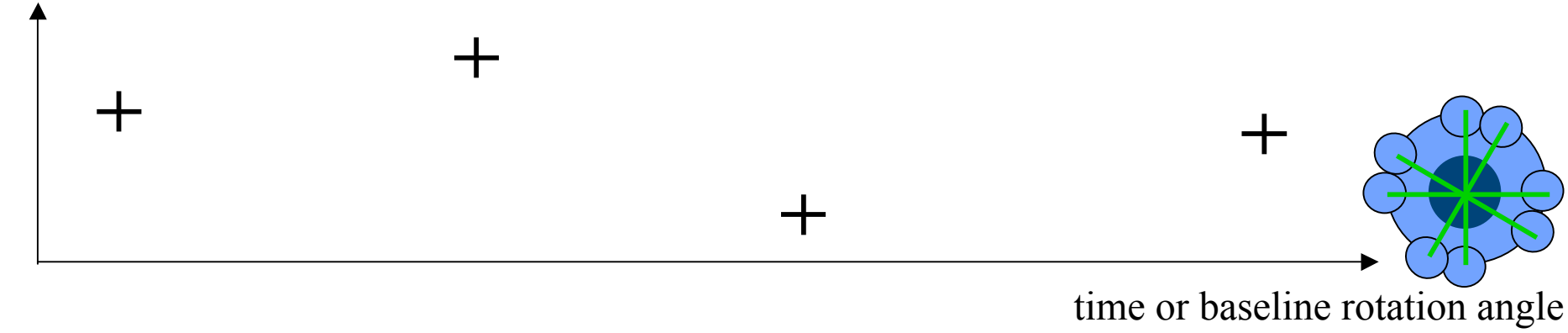
Will Deliver

- Structurally-Connected Interferometer concept for the *minimum* TPF science
- Formation-Flying Interferometer concept for the *full* TPF science
- Technology results, end-to-end simulation, and model validation to demonstrate viability of concepts

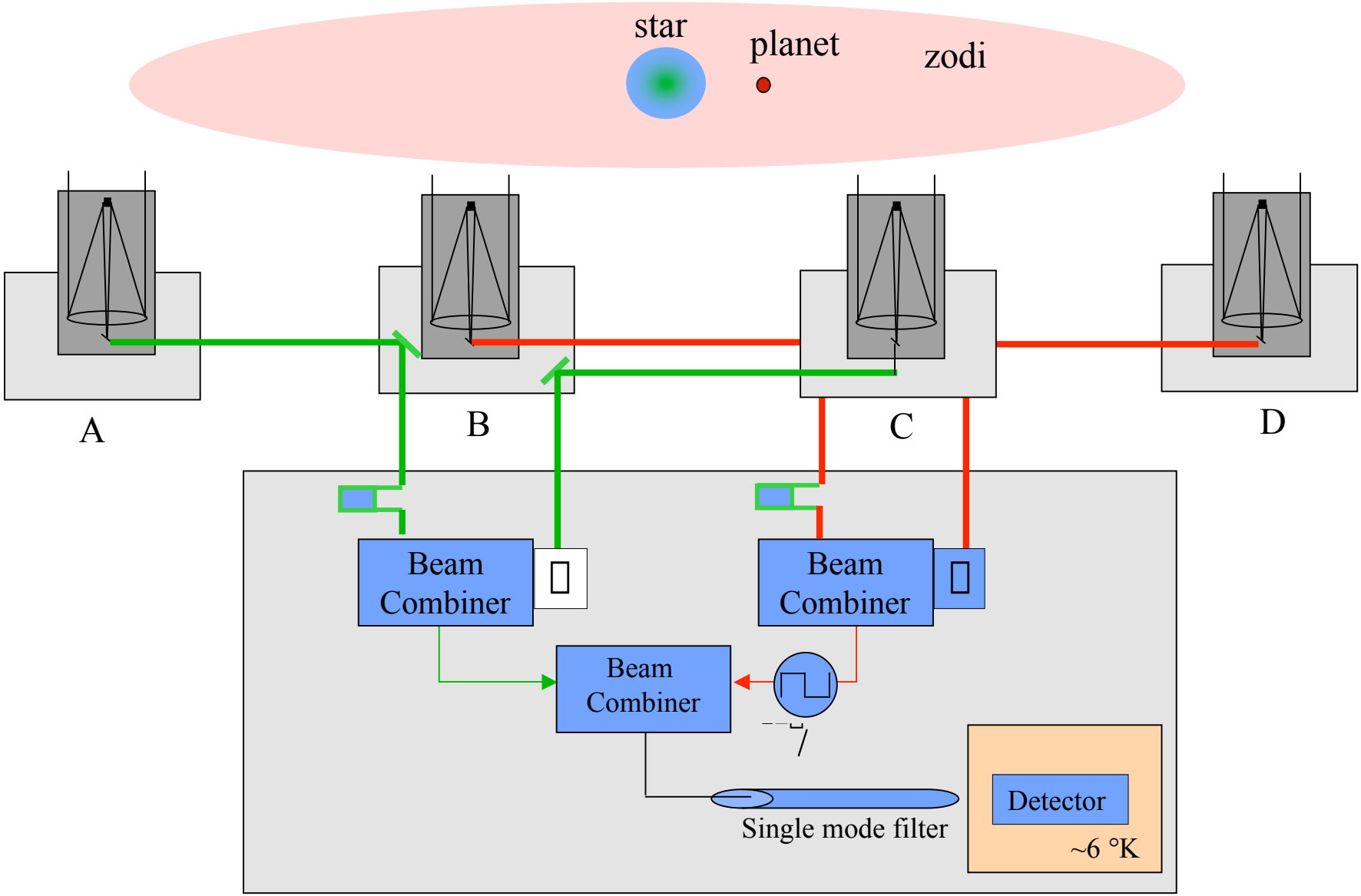
Interferometric Exo-Planet Detection



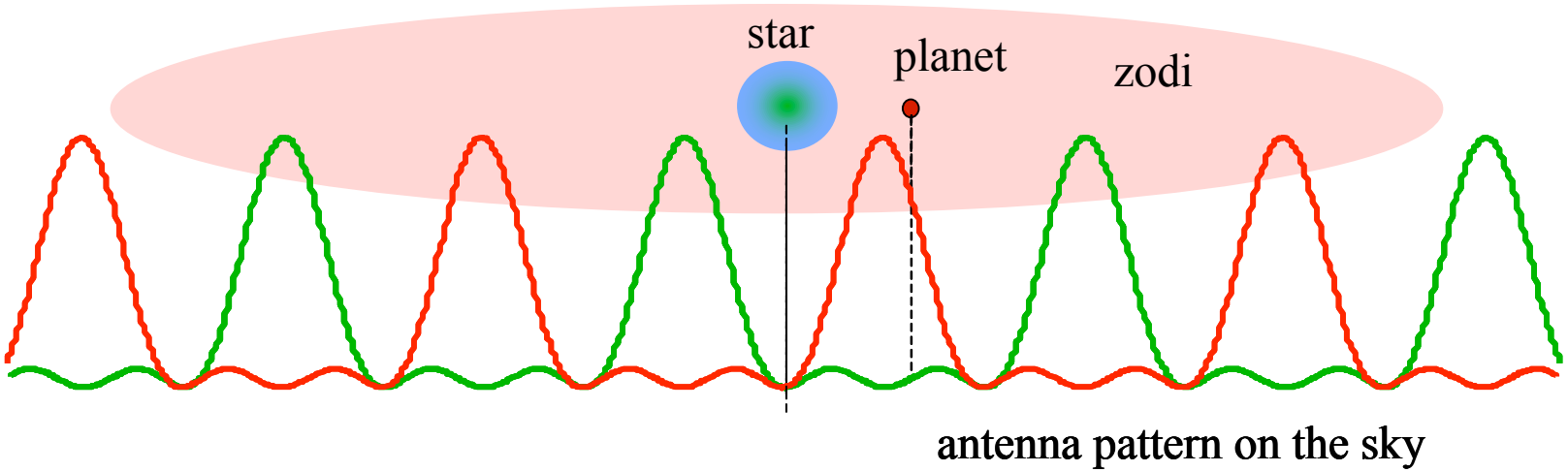
- Star is always on the dark fringe (null)
- Planet crosses the fringes as the baseline rotates:
  signal modulation due to planet

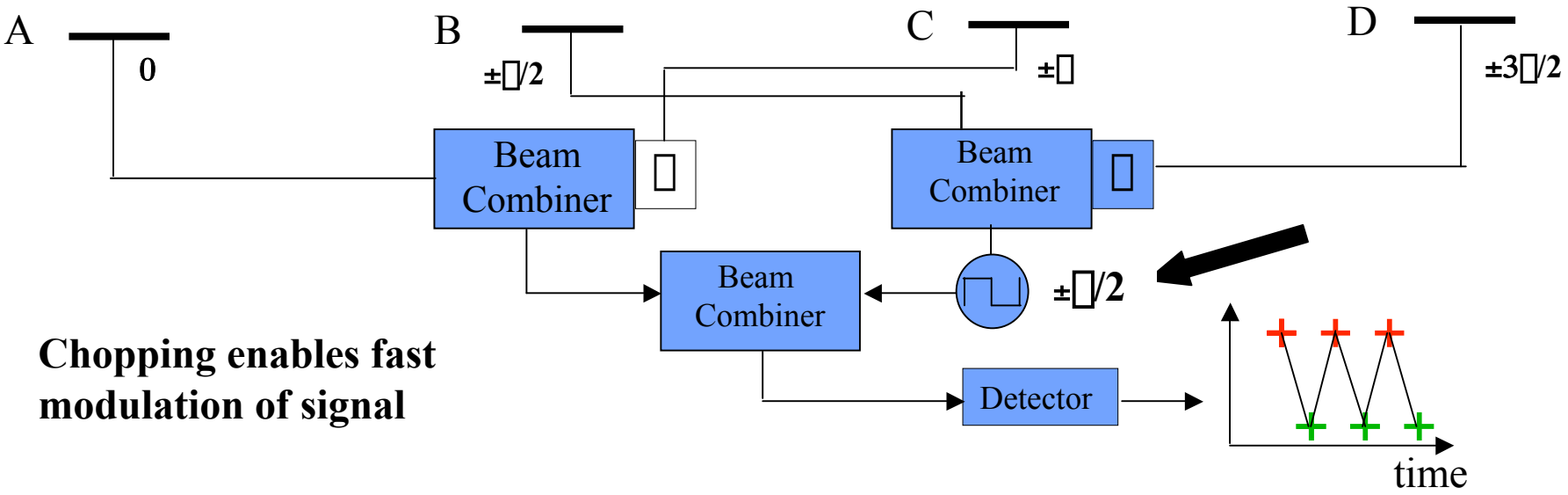


Dual Chopping Bracewell Nulling Architecture



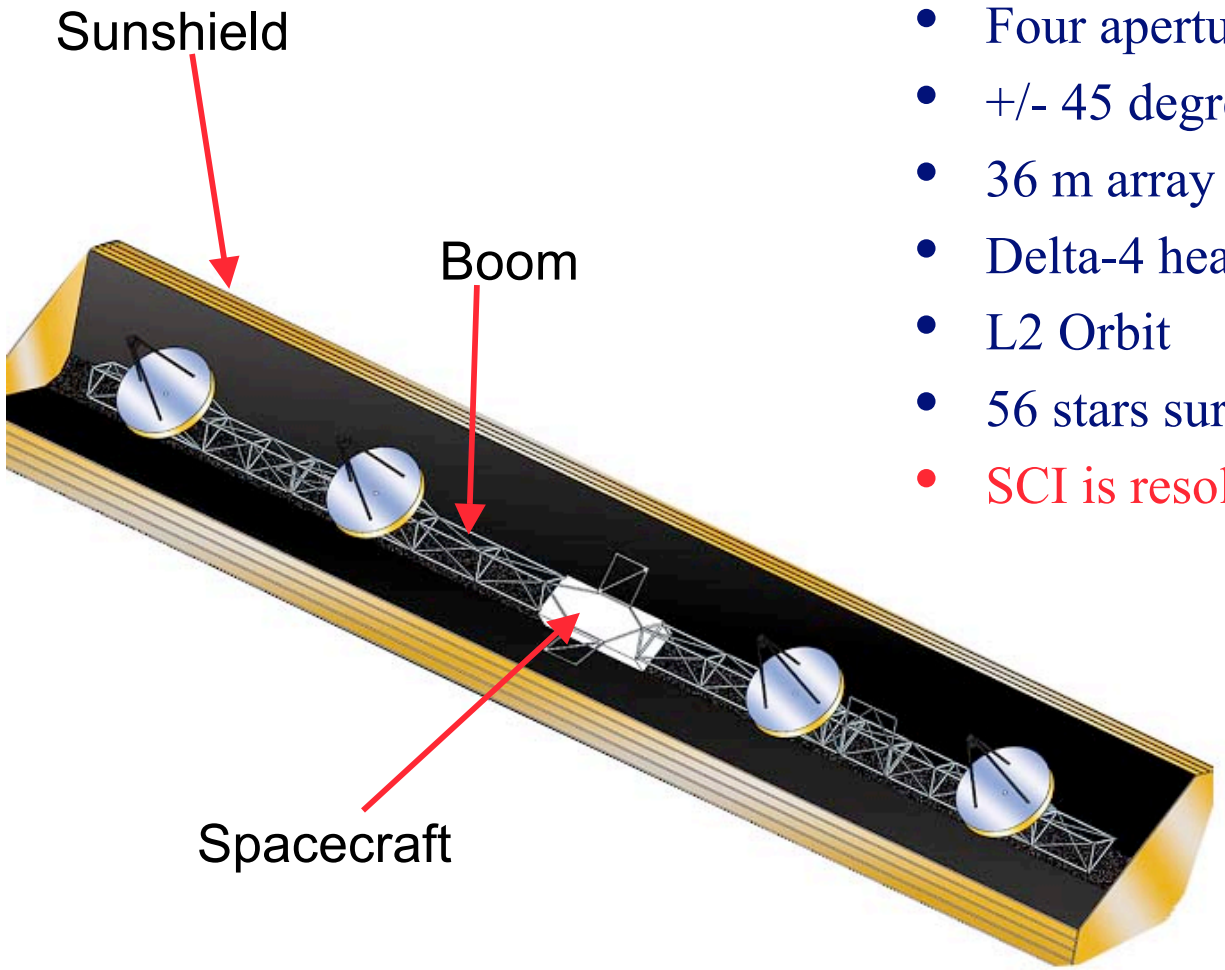
Chopping: a method for background suppression





Chopping enables fast modulation of signal

Strawman for Structurally-Connected Interferometer



- Dual-chopped Bracewell
- Four apertures, 3.2 m diameter
- +/- 45 degrees sky coverage
- 36 m array
- Delta-4 heavy, 22.4 m fairing
- L2 Orbit
- 56 stars surveyed in 2 years
- SCI is resolution-limited

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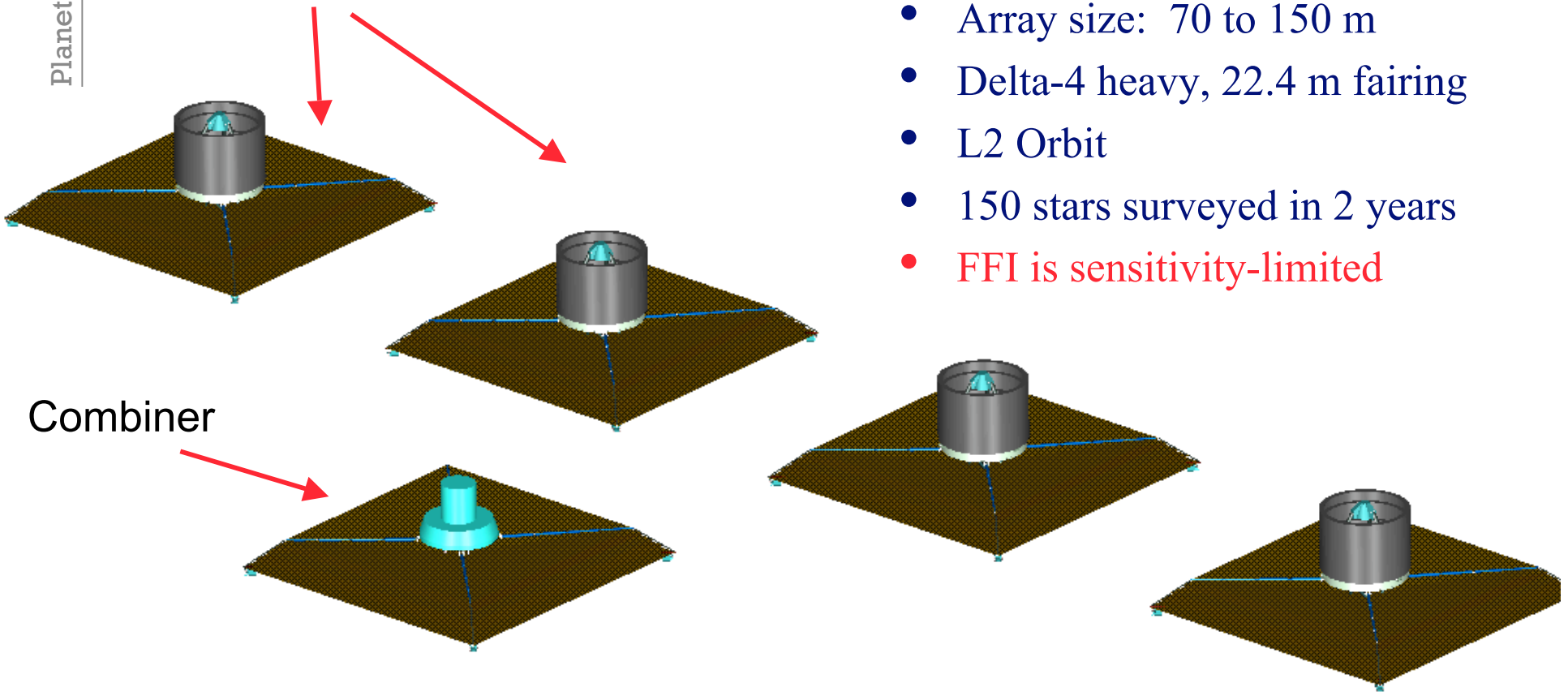
Formation Flying Interferometer Strawman

Planet Finder Mission



- Dual-chopped Bracewell
- Four apertures, 4.0 m diameter
- +/- 45 degrees sky coverage
- Array size: 70 to 150 m
- Delta-4 heavy, 22.4 m fairing
- L2 Orbit
- 150 stars surveyed in 2 years
- FFI is sensitivity-limited

Strawman Comparison

	Structurally Connected Interferometer	Formation Flying Interferometer
Science Capability		
Number of Stars	**56**	**150**
Science Assumptions		
Local zodi (MJy per sr, at 12 ? m)	**14**	**14**
Star List:	**modified Ebbets**	**modified Ebbets**
Engineering Assumptions		
SNR for Detection	**5**	**5**
Min Wingtip-to-Wingtip spacing (m)	**NA**	**10**
Number of visits	**3**	**3**
Inclination Factor = (IHZ / IWA)	**1.29**	**1.29**
HZ (au) for 95% completeness, half-earth area	**0.7-1.5**	**0.7-1.5**
Engineering Parameters (Derived)		
Nulling Architecture	**uneven DCB**	**even DCB**
Array size (m)	**36**	**70 to 150**
Number of apertures	**4**	**4**
Mirror diameter (m)	**3.2**	**4.0**
Sky coverage (+/- degrees, from anti-sun	**45**	**45**
Throughput	**5%**	**7%**
Integration Time / (2 yrs Calendar time)	**50%**	**75%**
Number of detectors	**1**	**2**

Collaboration with ESA

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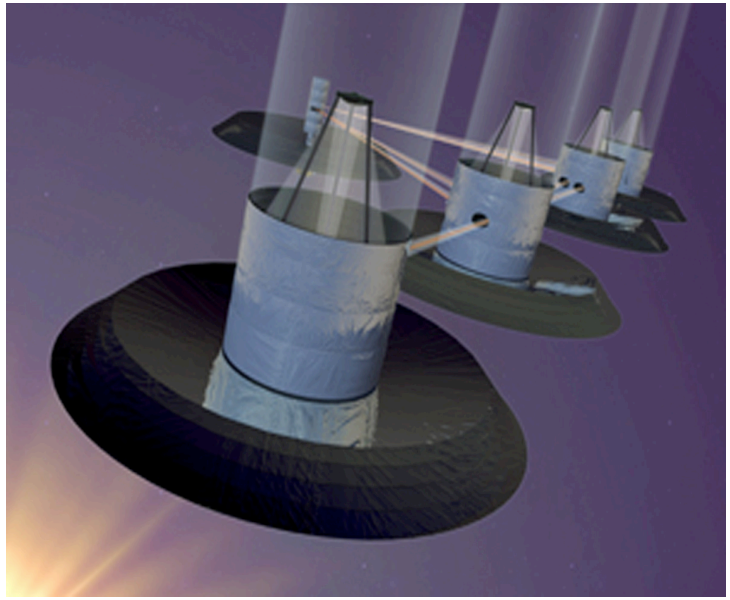
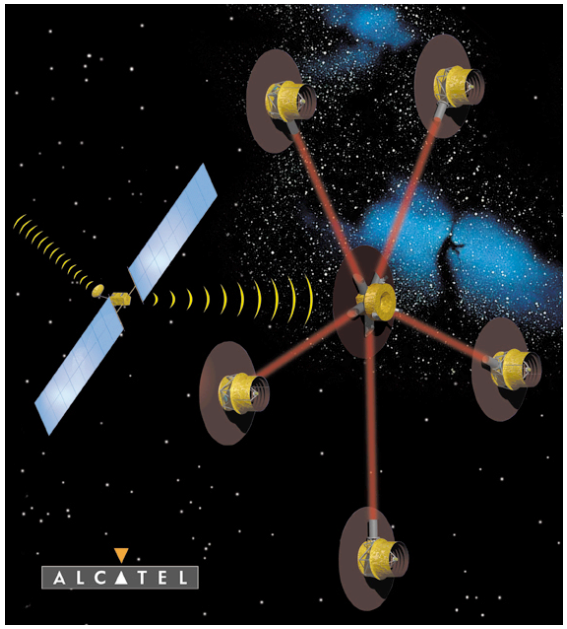
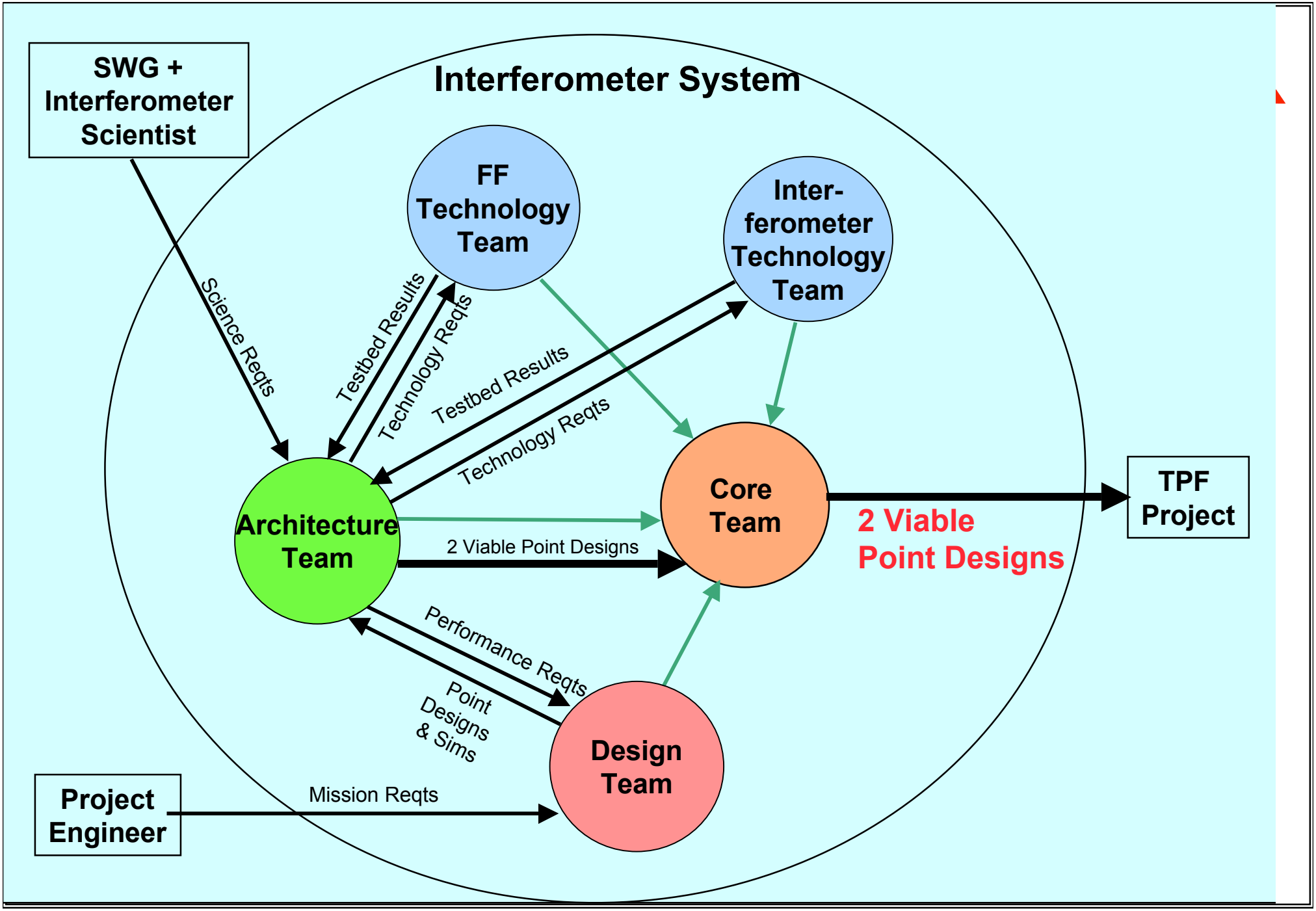
TPF Book Design



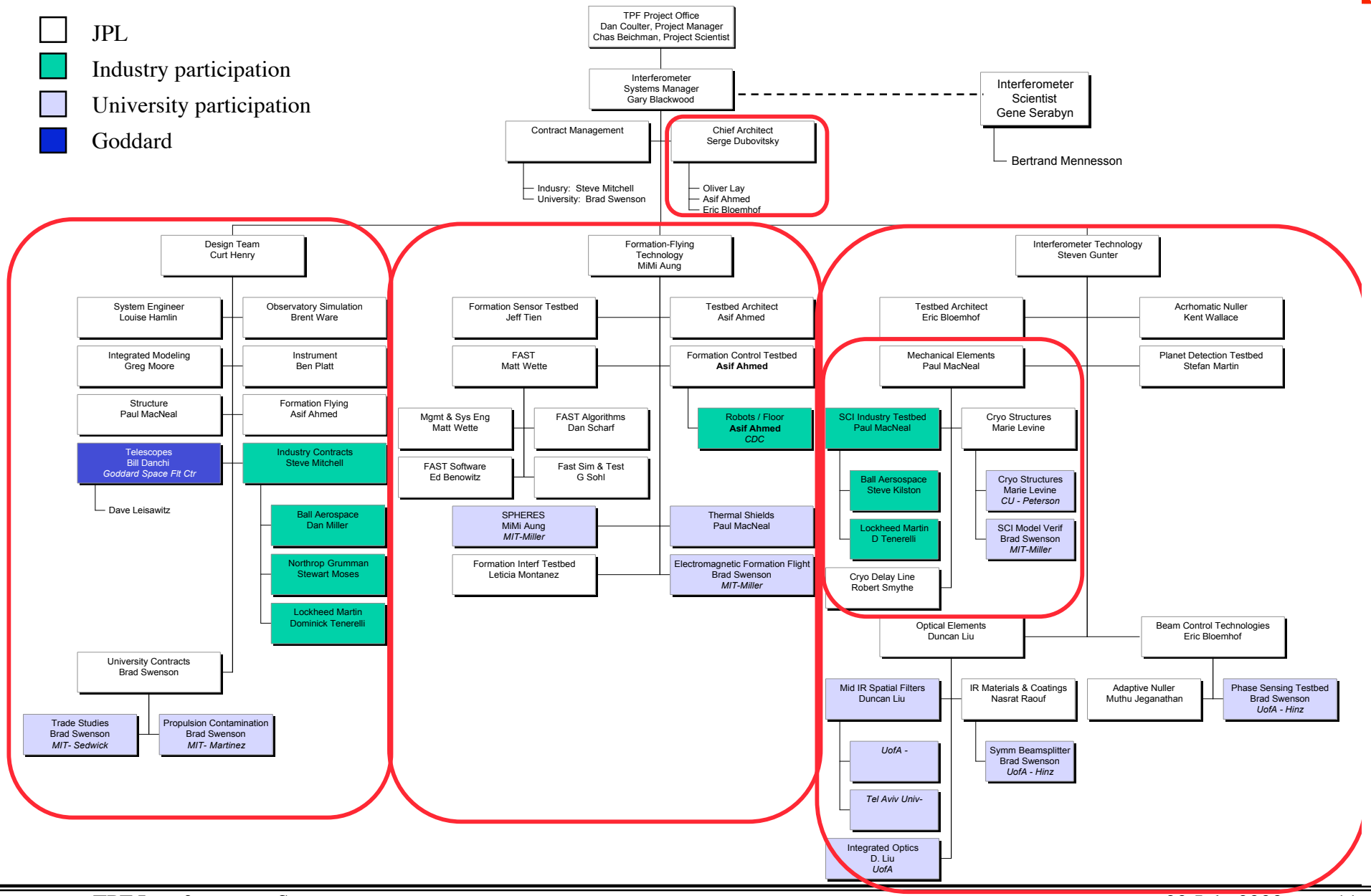
ESA - Darwin



- Objective – make common nulling architecture recommendation
- Figures of Merit:
  - Detection Sensitivity
  - Fuel Usage
  - Leakage suppression
  - Launch packaging
  - Beam combiner complexity
  - Array size


SWG + Interferometer Scientist
Interferometer System
FF Technology Team
Inter-ferometer Technology Team
Science Reqts
Testbed Results
Technology Reqts
Testbed Results
Technology Reqts
Architecture Team
Core Team
TPF Project
2 Viable Point Designs
2 Viable Point Designs
Performance Reqts
Point Designs & Sims
Design Team
Project Engineer
Mission Reqts

TPF Interferometer Systems

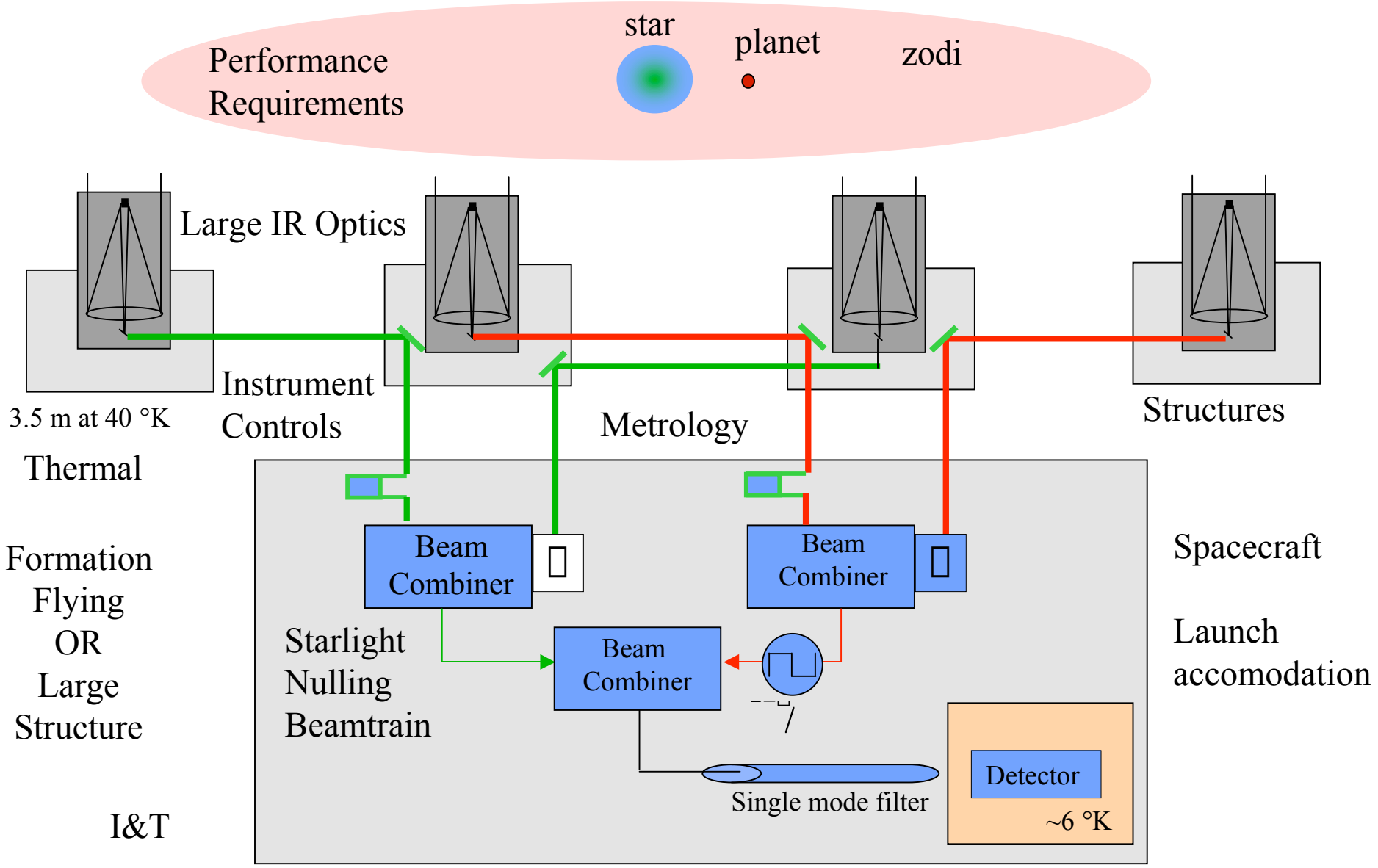


Top Technical Concerns: Kepner-Trego Method

- Concerns Prioritized by:
  - Gap (Seriousness) ➔compare Reqt to SOA
  - Urgency ➔ will it be a showstopper in 2006?
  - Trend ➔ is anyone else working on it?

- Top Concerns Mitigated by:
  - System Engineering ➔ Design Team
  - Technology Development ➔ Technology Teams
  - Inheritance ➔ Current, by 2006, by Phase C/D

Interferometer Building Blocks: Categories for Concerns



Technical Concerns (1 of 2)

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CORE

StarLight Nulling BeamTrain

- Nulling Architecture
- Beam Combination
- Internal Thermal Emissions
- Spatial Filters
- Intensity Matching
- Phase Control

Instrument Controls

- Pointing control of compressed beam
- Cryo Delay Line path stability

Detectors

- Cryocoolers

COMMON

Flight and Mission System

- Launch packaging of SCI and FFI
- Interspacecraft communications
- Sky coverage / thermal shield packaging

Integration and Performance Verification

- End-to-end flight system test
- Overall system complexity

Retired Primarily by Technology
Retired Primarily by System Engineering

Technical Concerns (2 of 2)

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CRYO STRUCTURE

Precision Cryogenic Deployed Structure

- Stability of long cold deployed structure
- Cryo hinge and latch stability
- Ability to predict on orbit performance – availability of modeling tools

FORMATION FLYING

Formation Flying System

- Long Term System Robustness
- Performance of Fine Formation Control
- Algorithm Functionality in Deep Space
- Coarse Acquisition Sensor

Formation Flying Accommodation

- RF Interference from thermal shield
- Inter spacecraft stray light

Retired Primarily by Technology
Retired Primarily by System Engineering

NOT on the **Top Concerns** List because of Inheritance

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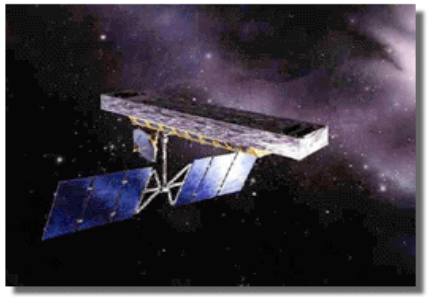
- Large IR optics
  - NGST
- Relative linear metrology
  - StarLight, SIM
- Absolute metrology
  - Code R: Distributed Spacecraft Technology program
- Detectors
  - SIRTF, NGST
- Passive cooling
  - NGST
- Knowledge of on orbit disturbances and environment
  - SIM, NGST, SIRTF, IPEX
- Microdynamic Disturbances
  - IPEX



SIM

NGST

SIRTF

Achromatic Nulling Testbed

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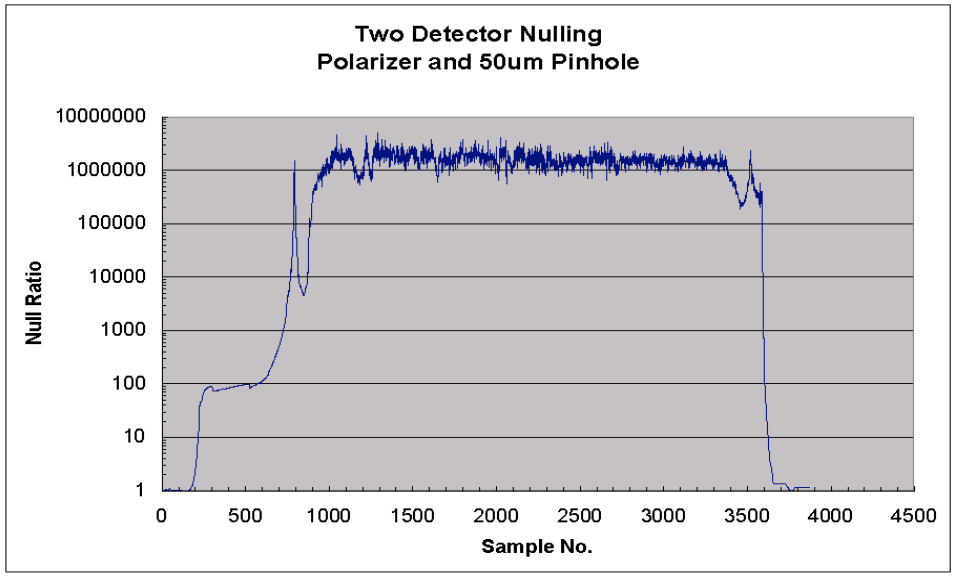
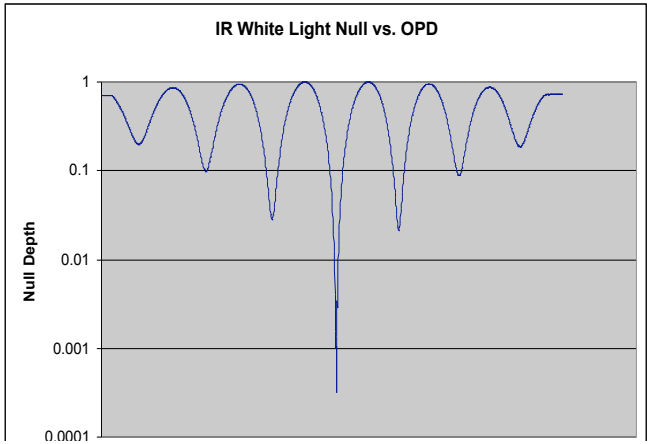
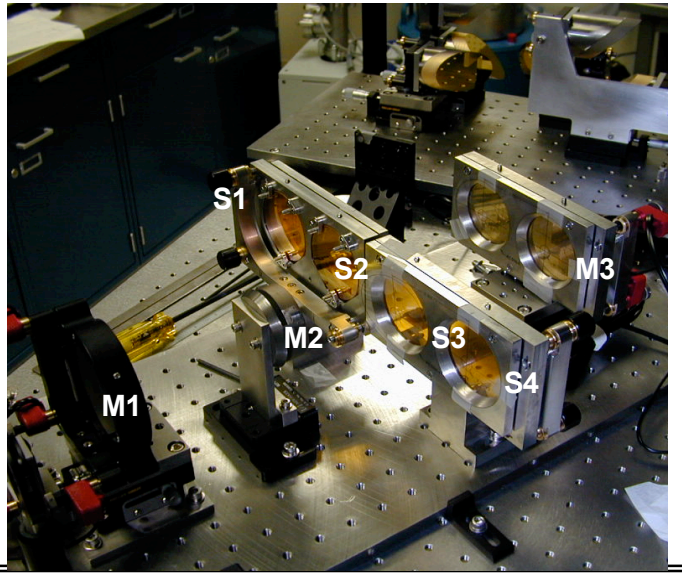
- Key Intended Result:
  - Stable 10^{-6} white light null with 50% bandwidth
- 7-12 μm

10^{-6} Laser Null, 10 μm



$4x10^{-4}$ WL Null, 20% bw

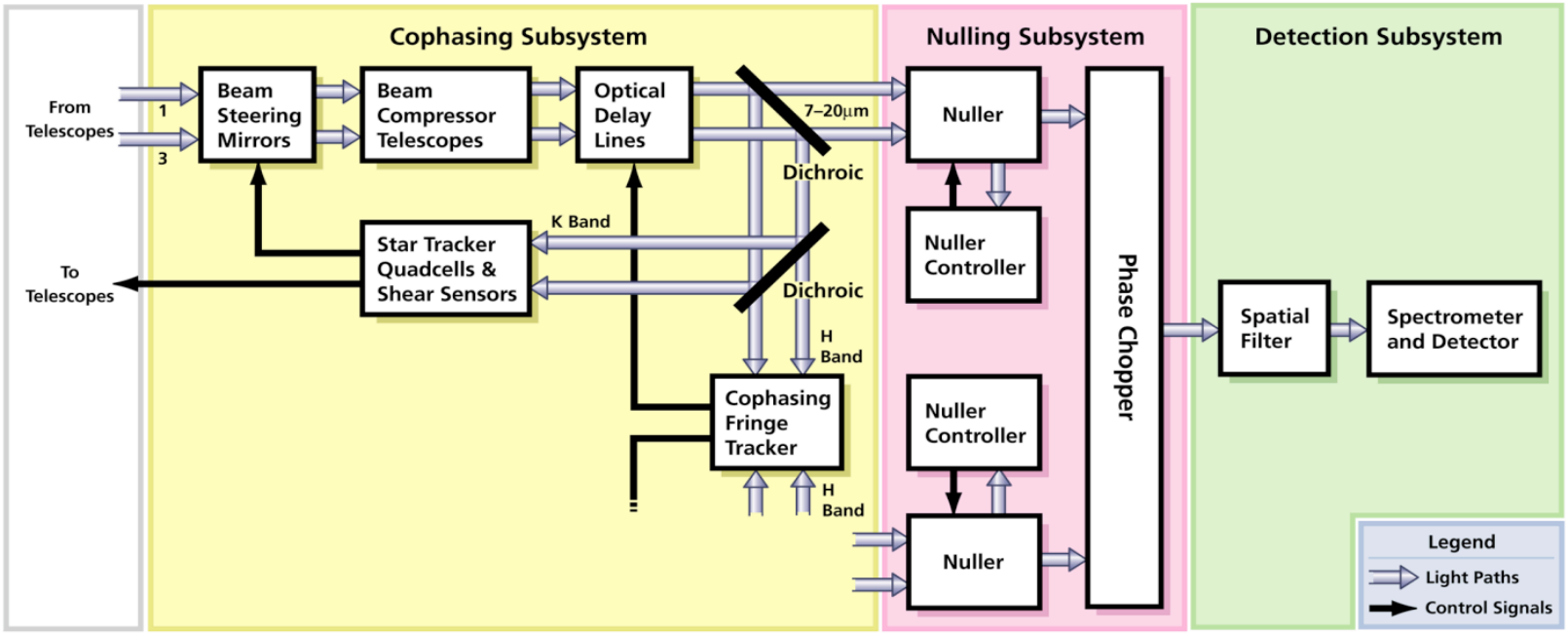




Planet Detection Testbed

- 4-beam demonstration of dual-chopped Bracewell
- Key intended result:
  - Planet extraction (10^{-6} planet/star contrast), at 10 um
  - 10^{-6} null depth
  - 10^{-7} null stability
  - Amplitude and phase control (0.4%, 4 nm)

Functional diagram of TPF nuller



Nulling and Planet Detection

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Core Interferometer Technology

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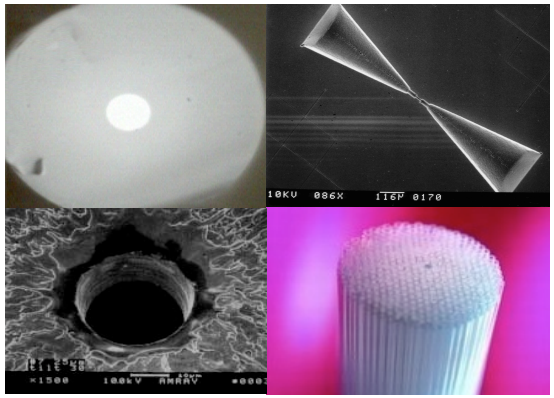
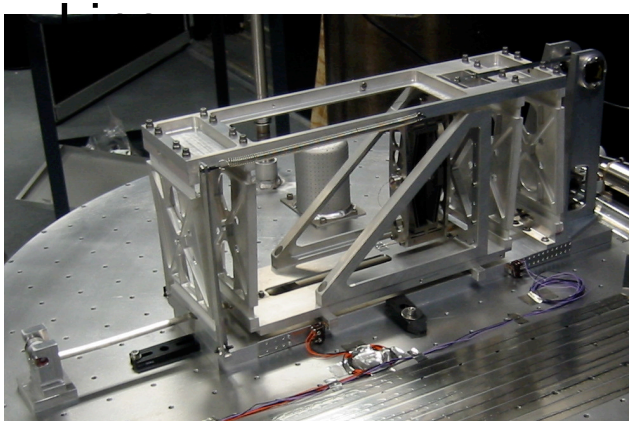
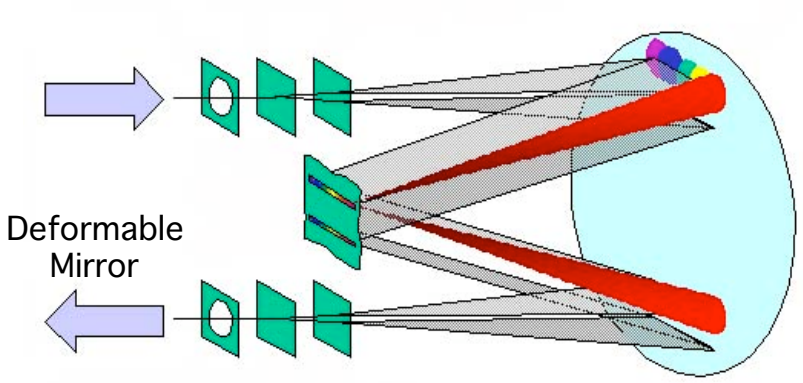
Mid-Infrared Spatial Filters



Cryogenic Delay



Adaptive Nuller



Cryogenic Structures Technology

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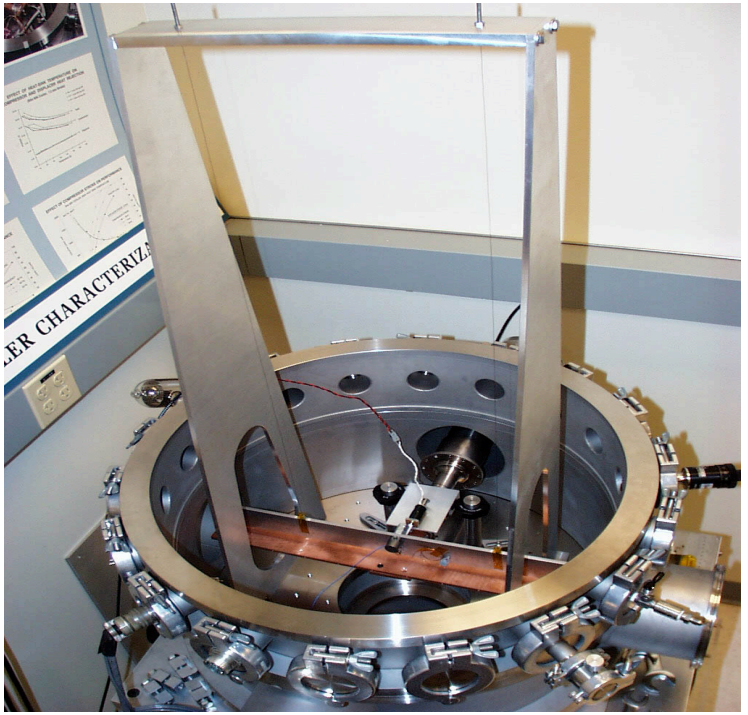
Structurally-Connected Interferometer Testbed

Cryogenic Structures Technology



Formation Flying Technology

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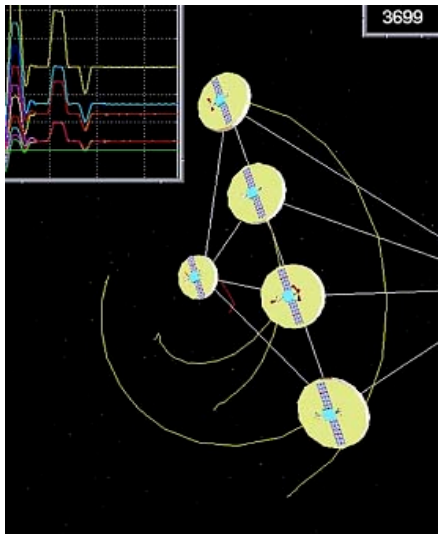
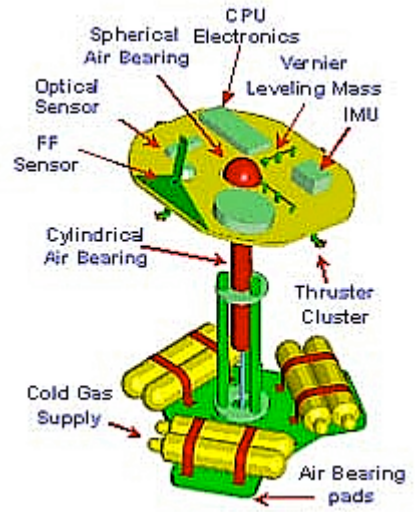
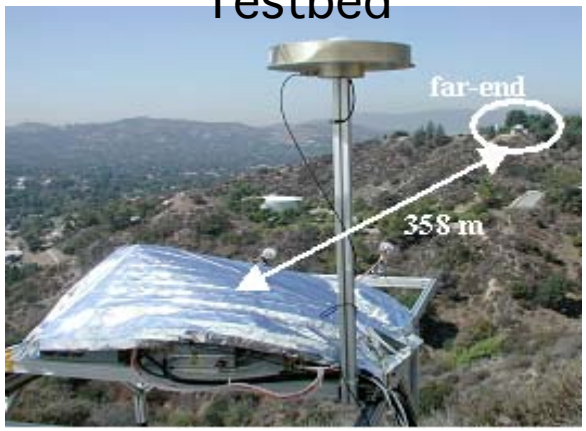
FAST



Formation Control Testbed



Formation Sensor Testbed



MIT SPHERES

Next Steps

- Architecture
  - Update concerns
  - Ensure testbed plan effectiveness
  - Nulling architecture recommendation with ESA
  - Science capability assessment (
- Design Team
  - Next level of design
  - Engineering Capability assessment
- Technology
  - Deliver results per plan
  - Meet interim milestones

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Summary

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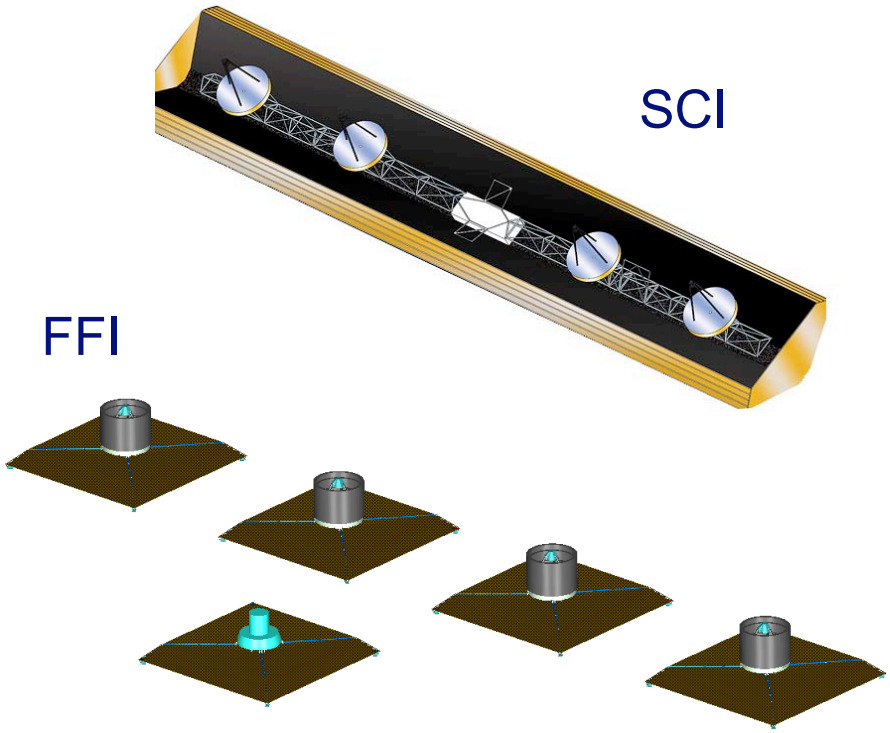
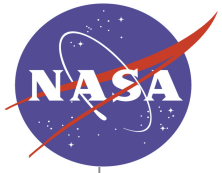


Interferometer Systems Will Deliver

- Structurally-Connected Interferometer concept for the *minimum* TPF science
- Formation-Flying Interferometer concept for the *full* TPF science
- Architecture Trades
- Concerns Identification / Mgmt
- Design Team
- Technology Development



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Backup

Top Concerns: Core Interferometry

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Category	Primary Concern	TPF Requirement
Starlight Nulling Beamtrain	Nulling architecture	Survey 30-150 stars for terrestrial planets
	Beam combination	4 or 6 beams, 10^{-5} null 6.5- 17□m
	Internal thermal emissions	<<100 photons/sec
	Spatial Filters	70% throughput in single mode, 6.5-17□m
	Intensity matching	0.2%
	Phase control	1nm (all frequencies)
Instrument Controls	Pointing control accuracy of compressed beam	50 mas
	Cryogenic delay line closed loop stability	0.1 nm at 40K
Detectors	Cryocoolers	30mW at 6K

Common Concerns

Category	Primary Concern	TPF Requirement
Flight & Mission System	Launch packaging of structure, formation flight systems	Self imposed
	Interspacecraft communications	Continuous reliable high data rate 4 Mbits/sec
	Sky coverage	At least +/- 45 deg
Integration and Performance Verification	End to end flight system test	Ability to verify multi-collector distributed flight system
	Overall system complexity	Acceptable risk

Top Concerns: Formation-Flying

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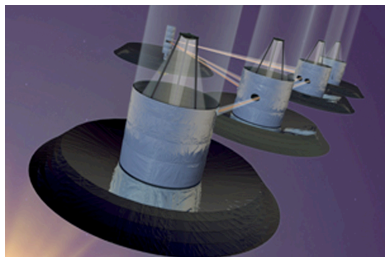
Category	Primary Concerns	TPF Requirements
Formation-Flying System	Long-term system robustness	5-10 years
	Performance of fine formation control	1 cm range, 20 arcsec bearing accuracy
	Algorithm functionality in deep space	5 s/c autonomous sensing collision avoidance performance
	Course acquisition sensor	50 cm, 1 deg, 4 sterarian FOV with no calibration maneuvers
Formation Flying Accommodation	RF interference from thermal shield	Low multipath effects on RF range measurements
	Inter spacecraft stray light	<<100 photons/sec



Top Concerns: Connected Structure

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Category	Primary Concern	TPF Requirement
Precision Cryogenic Deployed Structure	Stability of long Cryogenic structure	1nm, 36m, 40K
	Cryo hinge and latch stability	< 100m
	Structural modeling tools	Confident prediction of performance